

# **ADMIXTURES AS MODIFIERS OF THE PERFORMANCE OF AIR LIME MORTARS: AN OVERVIEW**

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**Lime mortars:** The most traditionally used type of mortars in the Built Heritage over centuries. These mortars are characterized by the use of lime, usually air lime, as the binding material. Nowadays, air lime can be applied in mortars as renders, repair mortars and other mixes.

**Lime classes** EN 459-1:2011, Building Lime Part 1: Definitions, specifications and conformity criteria:

Lime classes	CaO + MgO	MgO	CO <sub>2</sub>	SO <sub>3</sub>	Free lime
CL 90	≥ 90	≤ 5	≤ 4	≤ 2	-
CL 80	≥ 80	≤ 5	≤ 7	≤ 2	-
CL 70	≥ 70	≤ 5	≤ 12	≤ 2	-
DL 85	≥ 85	≤ 30	≤ 7	≤ 2	-
DL 80	≥ 80	≤ 5	≤ 7	≤ 2	-
HL 2	-	-	-	≤ 3	≤ 8
HL 3.5	-	-	-	≤ 3	≤ 6
HL 5	-	-	-	≤ 3	≤ 3

**One of the main application field of the air lime mortars is the obtaining of**

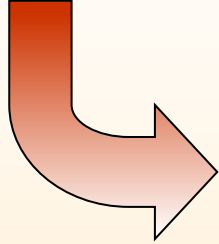
## **MORTARS FOR RESTORATION OF BUILT HERITAGE**

So far, cement mortars have been widely used due to the lack of awareness on

- lime mortar performance
- detrimental effects of the cement mortars on the old masonry  
(large amounts of soluble salts and too high mechanical strength for old masonry)

Many interventive processes carried out at the first and medium part of the 20th century with cement mortars have been proved to cause damage to the old masonry. Re-intervention aimed to withdraw the cement mortar.

## WHY SHOULD WE USE LIME MORTARS FOR RESTORING A HISTORIC BUILDING?



### ADVANTAGES OF LIME MORTARS

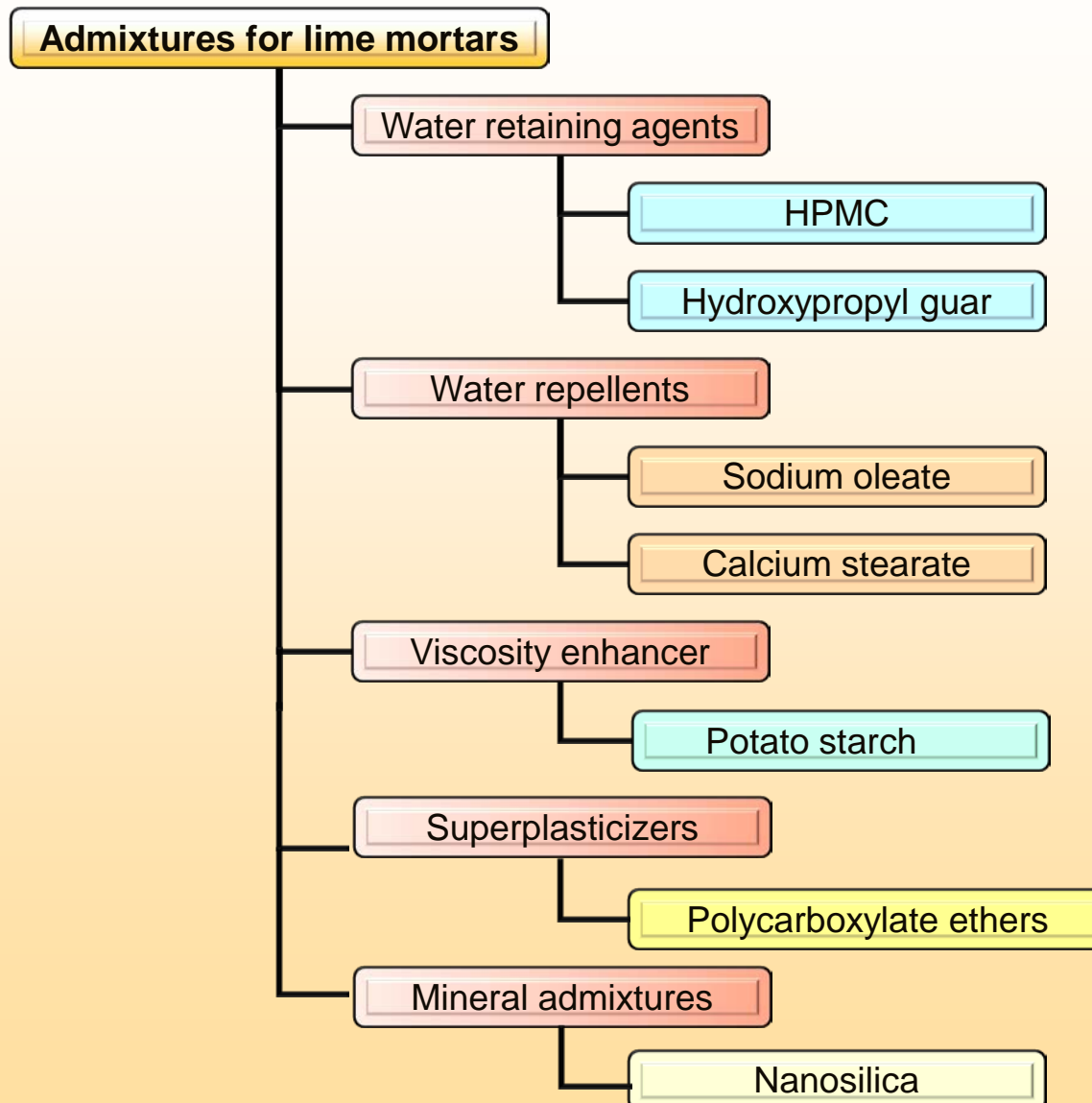
Their use has been strongly recommended by International centres such as ICOMOS, ICCROM, Venice Chart

- Low amount of soluble salts
- No expansive
- Strength compatible with masonry
- High degree of compatibility with ancient materials (old mortars, stones ...)
- Self-healing properties by dissolution /precipitation of the calcite

However, **SOME DRAWBACKS** still remain associated to the use of air lime mortars:

- Relatively low mechanical strengths.
- Long setting and hardening times, which hinder their application in modern works due to tight deadlines.
- Shrinkage phenomenon due to major volumetric changes with subsequent appearance of cracks and fissures.
- High water absorption capacity through capillarity, which leads to low durability in the face of freeze-thaw cycles.

**the use of admixtures can be helpful to overcome some drawbacks related to the use of air lime mortars!!**



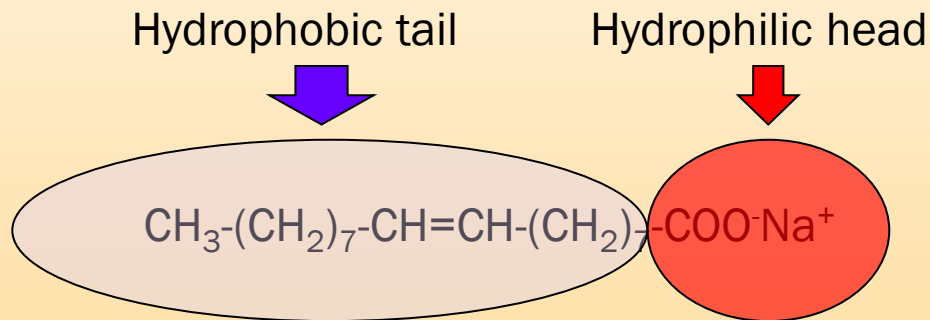


**Water repellents: AEAs air-entraining agents**

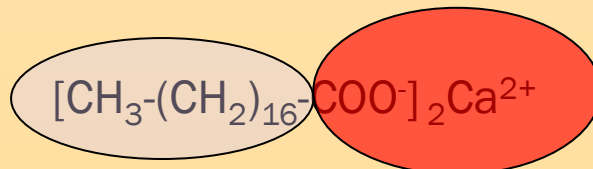
## Water repellents: AEAs air-entraining agents

- Main action: to reduce the absorption of water by capillarity
  - Secondary effect: to increase the entrained air
- Workability improvement
  - Lower density
  - Enhancement of durability in the face of freeze-thaw processes

- Sodium oleate (SO)



- Calcium stearate (CS)





## Water repellents: AEAs air-entraining agents



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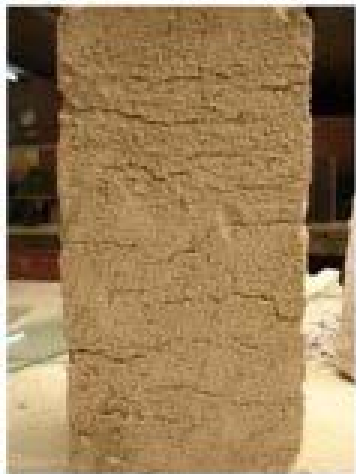
	Mixing water (g)	Open time (min)	Entrained air (%)
REF	410	195	2.8
SO-1 (low dosage)	400	157	4.2
SO-2 (high dosage)	440	465	4.2
CS-1 (low dosage)	420	235	3.7
CS-2 (high dosage)	440	960	3.4

## Water repellents: AEAs air-entraining agents



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Evolution of freshly applied mortars on bricks.



a)

REF



b)

SO-1



c)

SO-2



d)

CS-1



e)

CS-2

Fail caused by low adherence

Best performance: reduced number of superficial cracks

## Water repellents: AEAs air-entraining agents

	Density (g/mL)	Capillary coefficient (kg/m <sup>2</sup> min <sup>1/2</sup> )	Permeability coefficient
REF	1.67	2.36	16.6
SO-1 (low dosage)	1.61	0.58	15.3
SO-2 (high dosage)	1.58	0.06	14.9
CS-1 (low dosage)	1.65	1.59	20.8
CS-2 (high dosage)	1.62	1.40	15.7

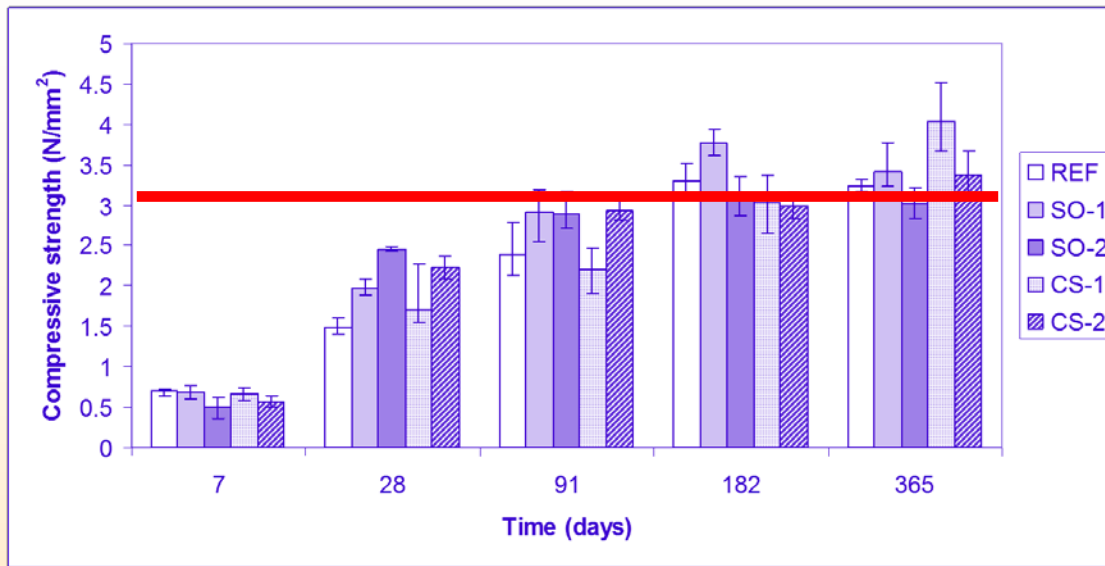
### Possibilities for the action mechanism:

- air bubbles might block the capillary pores, preventing them from absorbing water
- anionic surfactants inside pores might smooth their inner surface, modifying the water adsorption ability by the hydrophobic part of the surfactant
- the simultaneous action of both factors could also cut off capillary function.

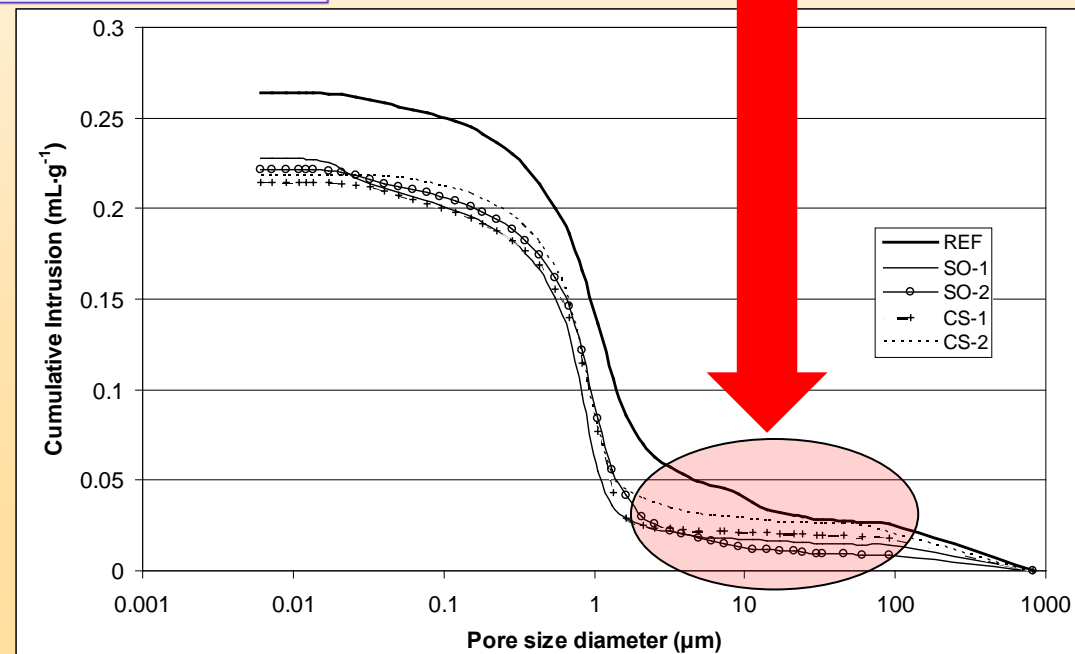
# Water repellents: AEAs air-entraining agents



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Blockage of pores 10-100  $\mu\text{m}$

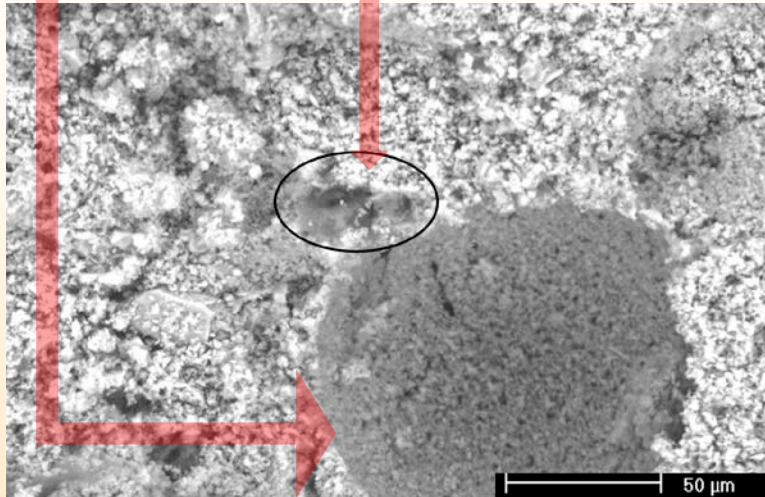


## Water repellents: AEAs air-entraining agents

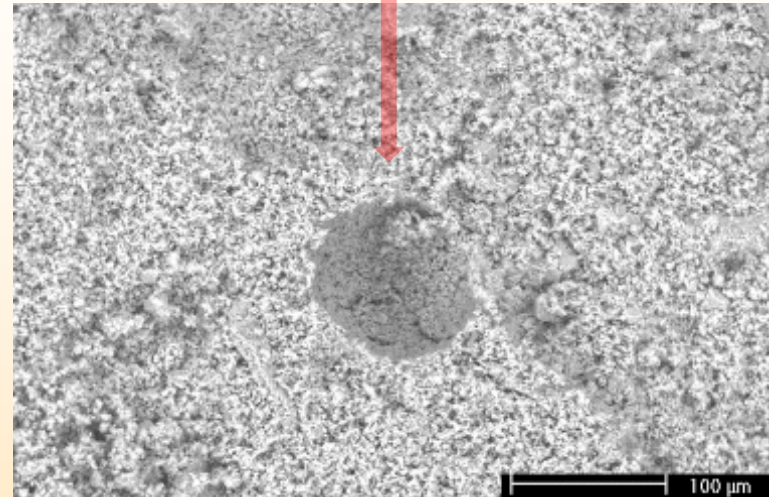


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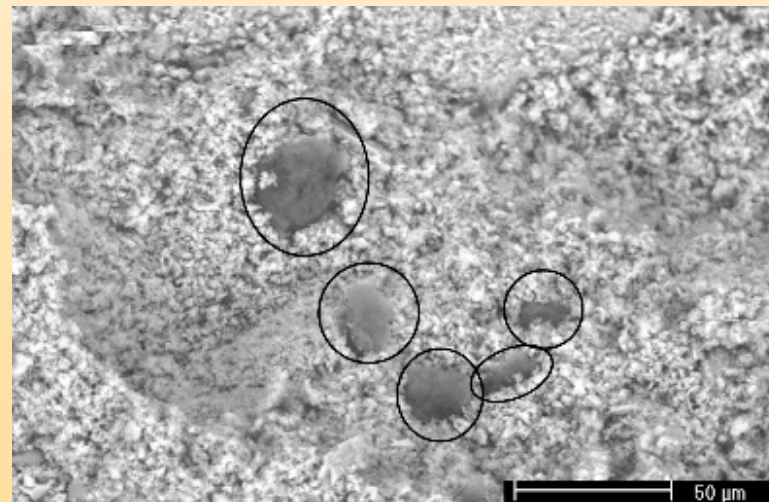
air void with **calcium oleate** sediment



air void in CS-2 sample

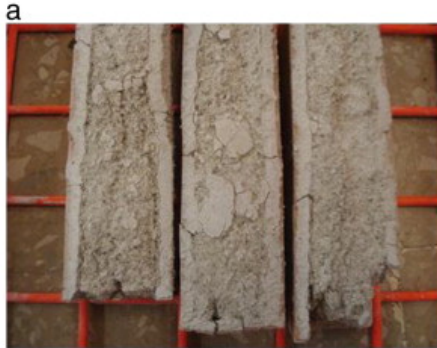


group of **calcium stearate** deposits in CS-2 sample.

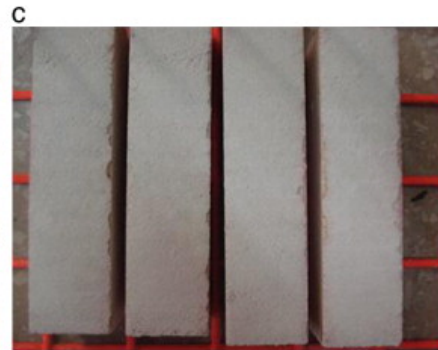
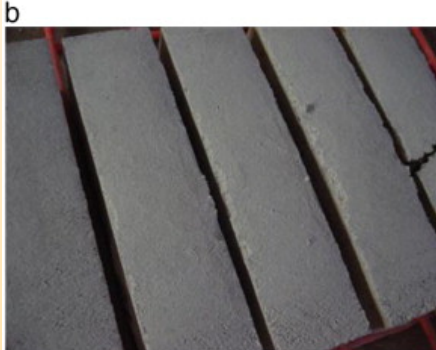




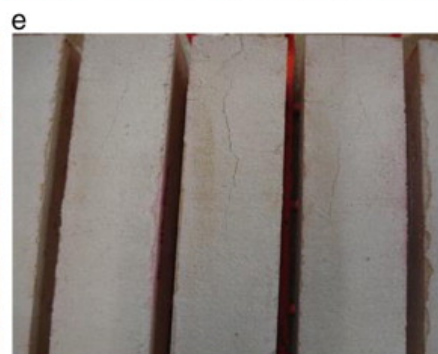
## Mortars after freezing–thawing cycles



a) Water repellent-free specimens after **6 cycles**, clearly destroyed



b) SO-1 samples after **6 cycles**, mainly intact; c) SO-2 samples after **14 cycles**, without any sign of deterioration



d) CS-1 mortars after **6 cycles**, destroyed; e) CS-2 specimens after **6 cycles**, clearly improved with respect to the reference.

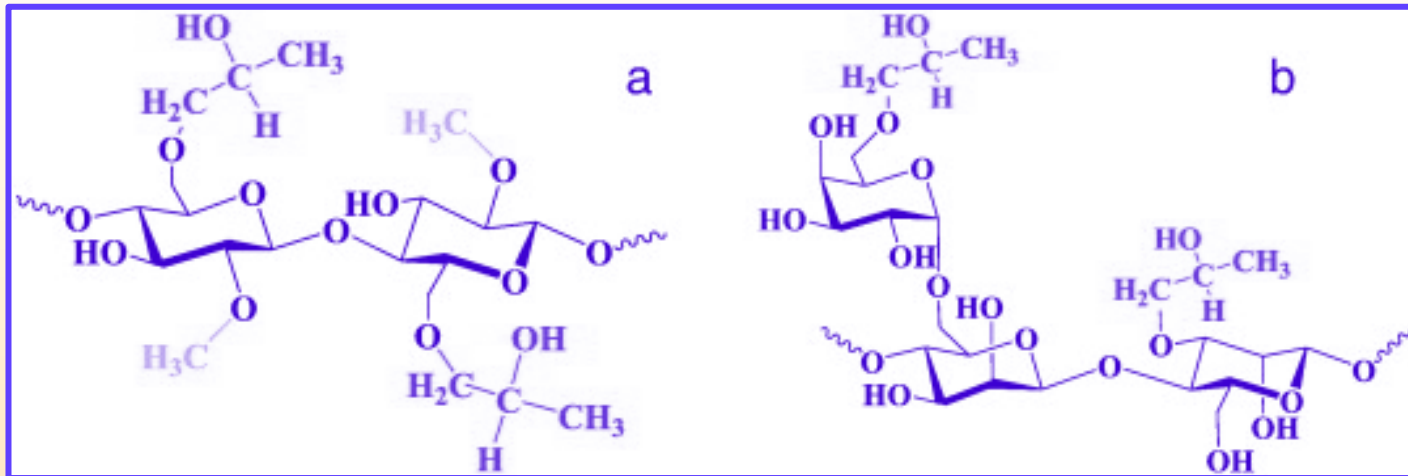


## **HPMC and hydroxypropyl guar: water retaining admixtures**

# HPMC and hydroxypropyl guar: water retaining admixtures



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Hydroxypropyl methylcellulose

Hydroxypropyl guar



# HPMC and hydroxypropyl guar: water retaining admixtures



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Lime is a very retentive  
material

	Density (g/L)	Air content (%)	Water- retention capacity (%)	Setting time (minutes)
REF	1942.5	2.8	94.3	195
HPMC	1842.5	3.4	91.9	630
HPG	1869.6	5.0	98.4	870

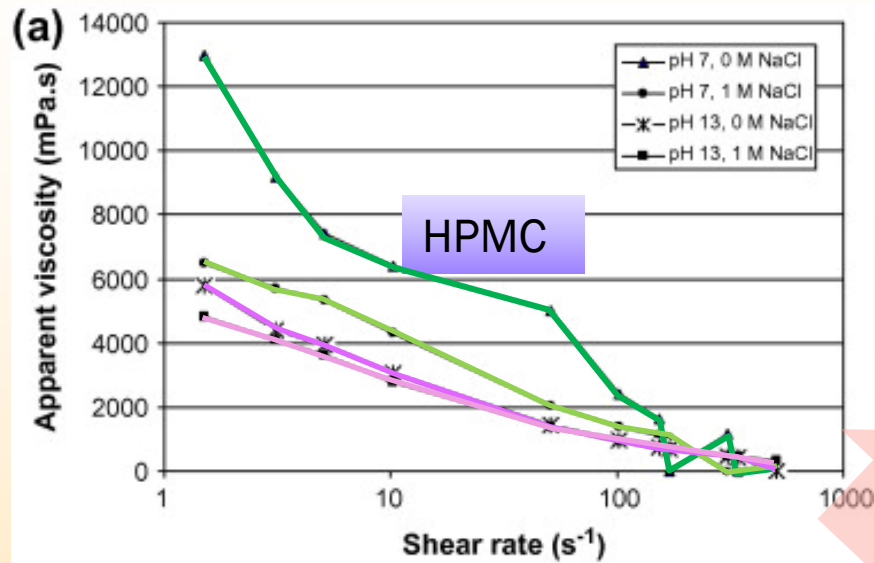
Rise in the air content due  
to surfactant properties

HPG improved the water  
retention but, surprisingly,  
HPMC worsened it.

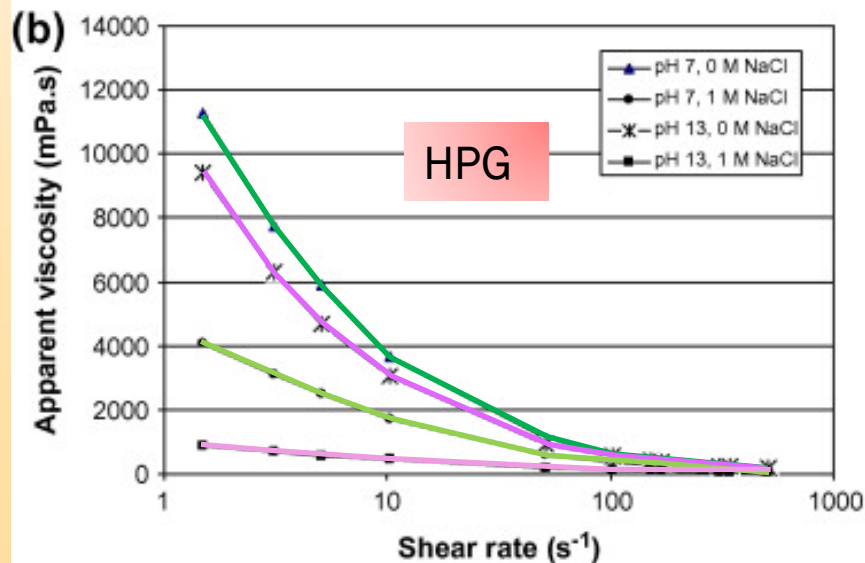
# HPMC and hydroxypropyl guar: water retaining admixtures



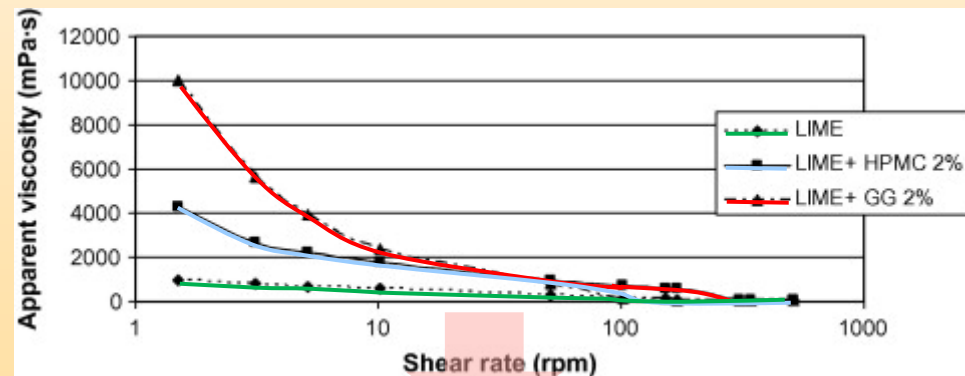
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- Shear-thinning behaviour: reduction in viscosity with increasing shear rate
- Reduction in viscosity at high pH values, as ionization of  $-OH$  groups resulted in electrostatic repulsions between polymer chains
- The larger number of  $-OH$  groups of HPG caused a strongest reduction



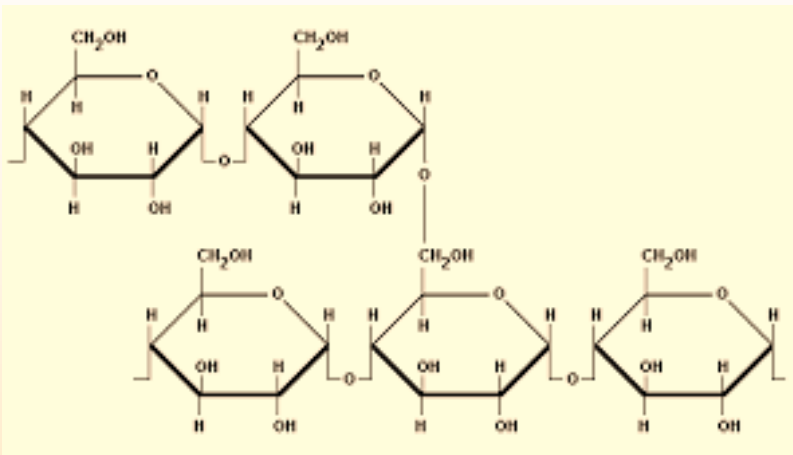
## Viscosity of lime pastes



- When slaked lime was added, the trend was inverted: HPG increased the viscosity owing to the  $Ca^{2+}$  ions cross-linking phenomenon

**Viscosity enhancer: potato starch**

## Viscosity enhancer: potato starch



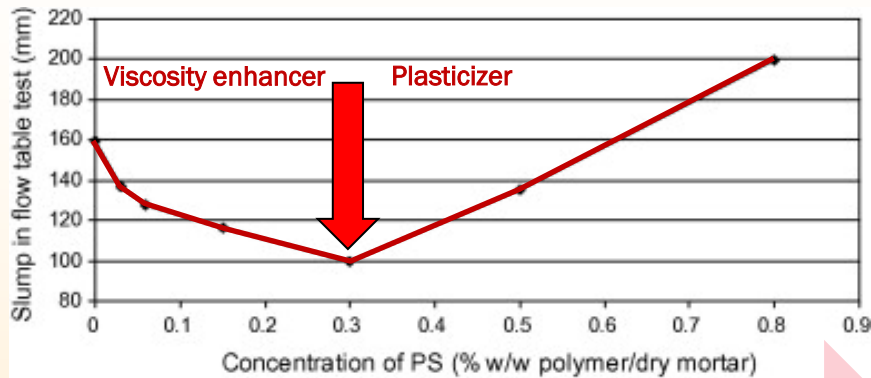
Low amylose starch

- **Main action:** The **thickening effect** is supposed to give non-sag and anti-slip properties to the mixtures, improving the pump ability in spray-on mortars.
- **Action mechanism** (strongly dependent on the molecular weight ):
  - Viscosity enhancer: increasing the water retention and giving rise to an interlocked structure through **hydrogen bonds**

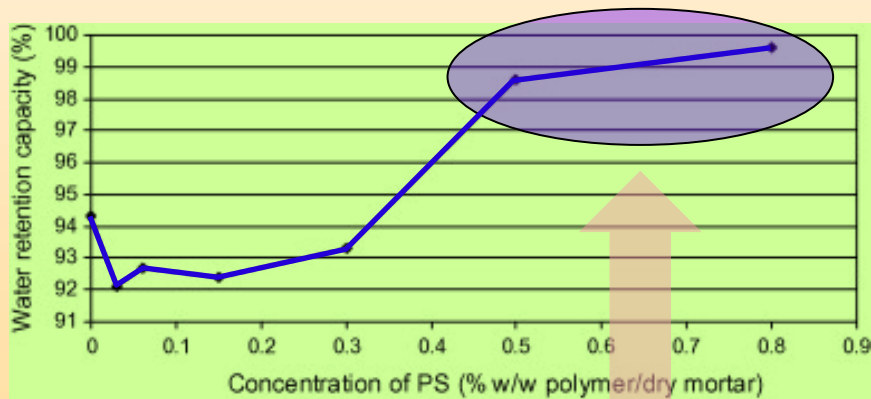
# Viscosity enhancer: potato starch



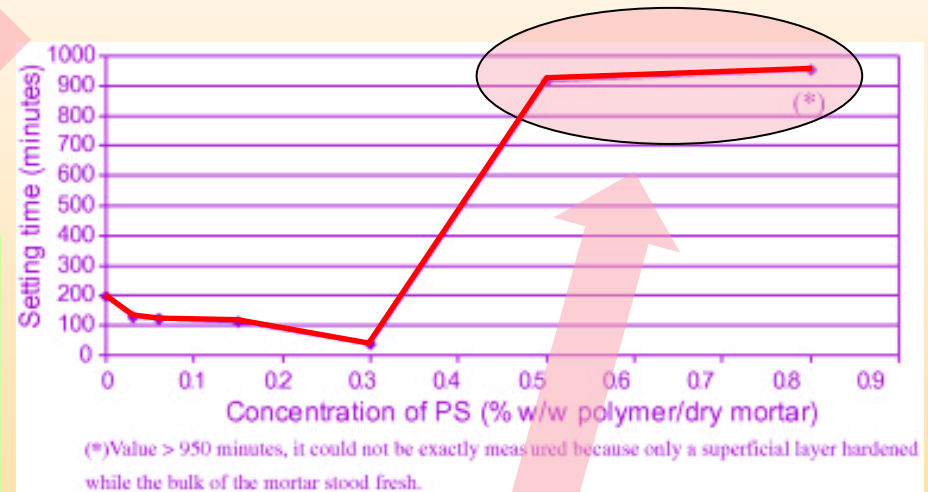
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Increasing dosage of the starch



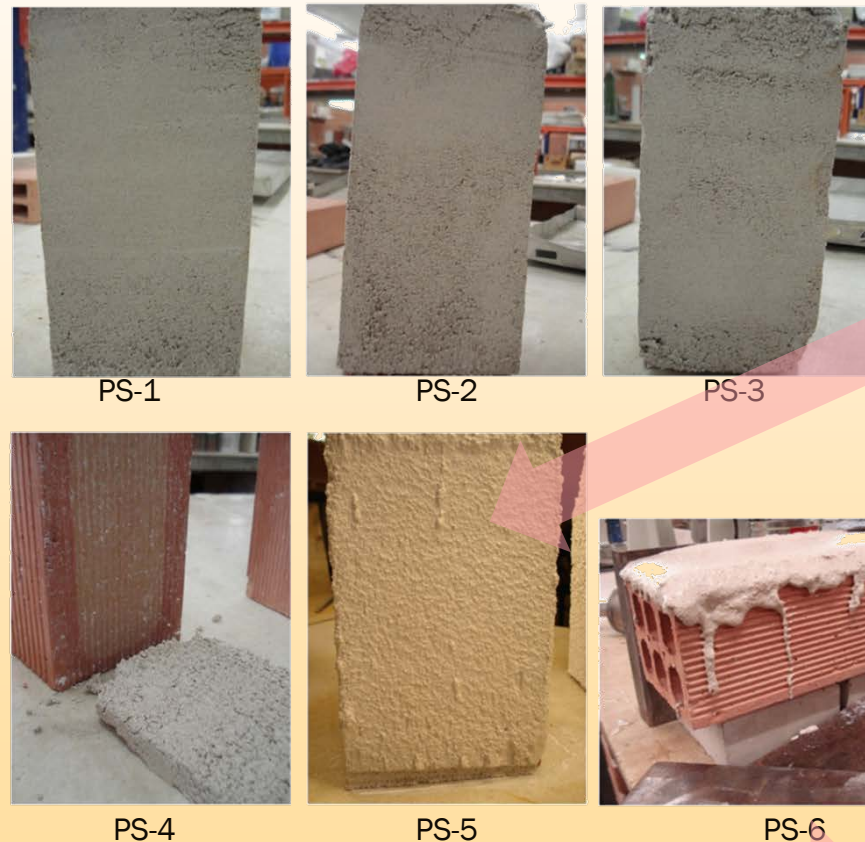
Larger water retention capacity  
for large dosages



Long delay in setting time

## Viscosity enhancer: potato starch

When spread over an absorbent support (a brick in this case), the presence of increasing dosages of PS helps to minimize the shrinkage phenomenon owing to the water loss. PS5 was the best dosage, whereas an excess of admixture yielded a too liquid mortar.



**Dosage 0.5%  
with the best  
performance**

REF

**Superficial cracks**

**Increasing dosage of the starch**



## Mortars after freezing–thawing cycles

REF mortar after **4 cycles**, with  
clear signs of deterioration



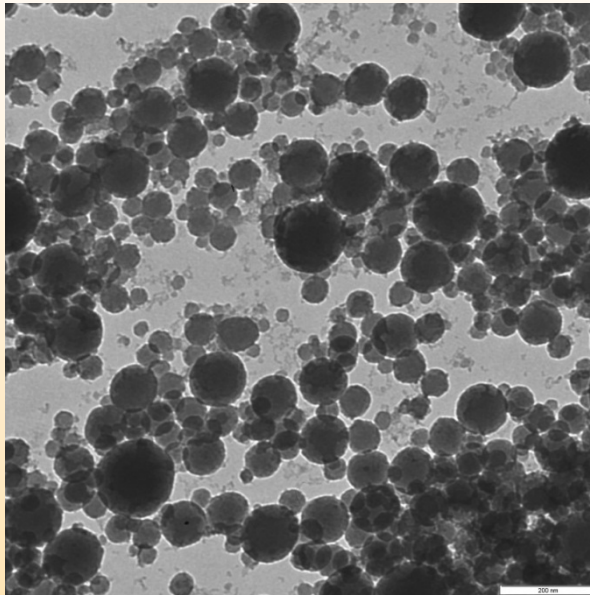
PS mortars after **4 cycles**,  
clearly less affected than REF  
mortars



**Pozzolanic addition: nanosilica**



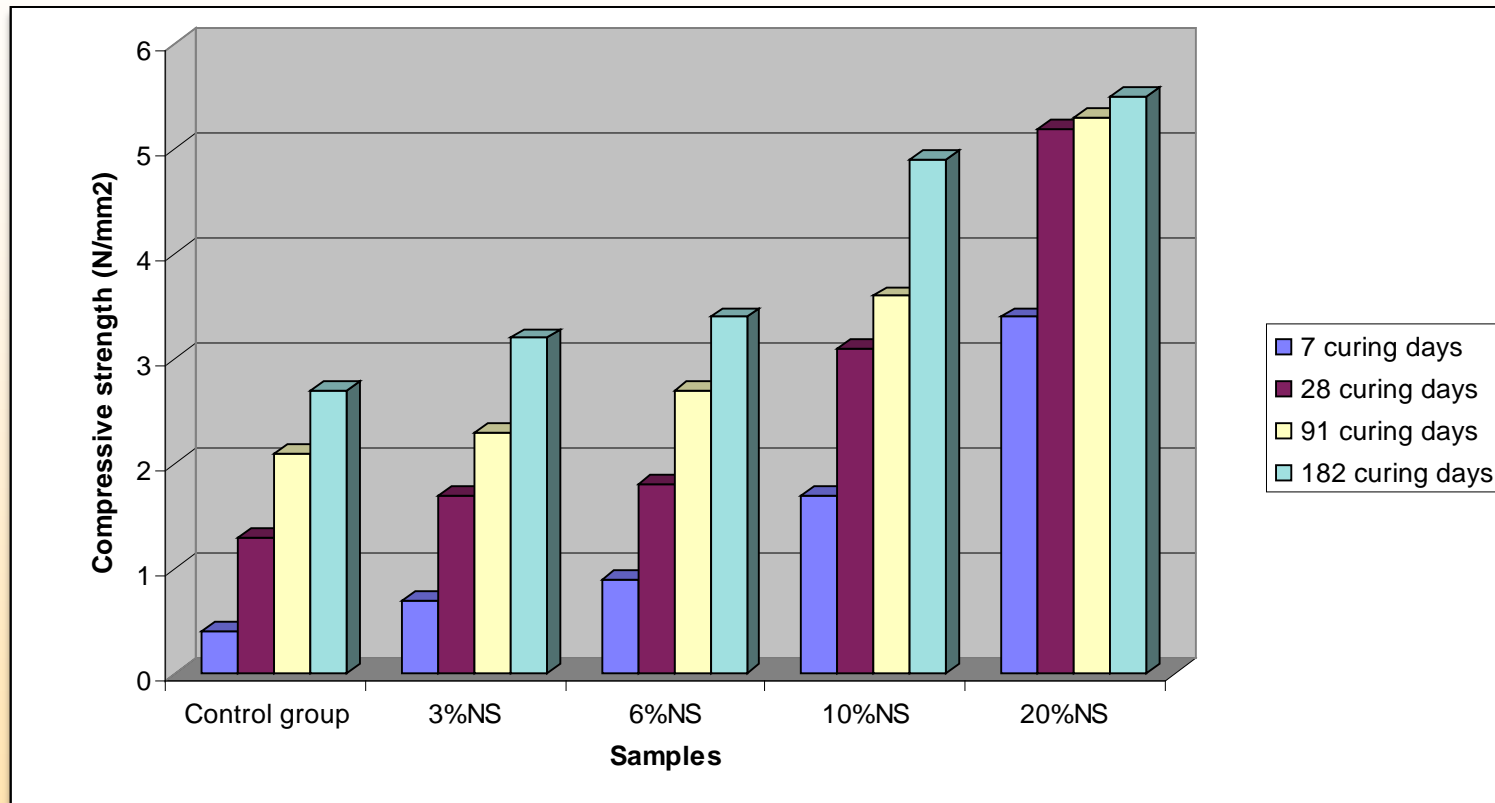
## Pozzolanic addition: nanosilica



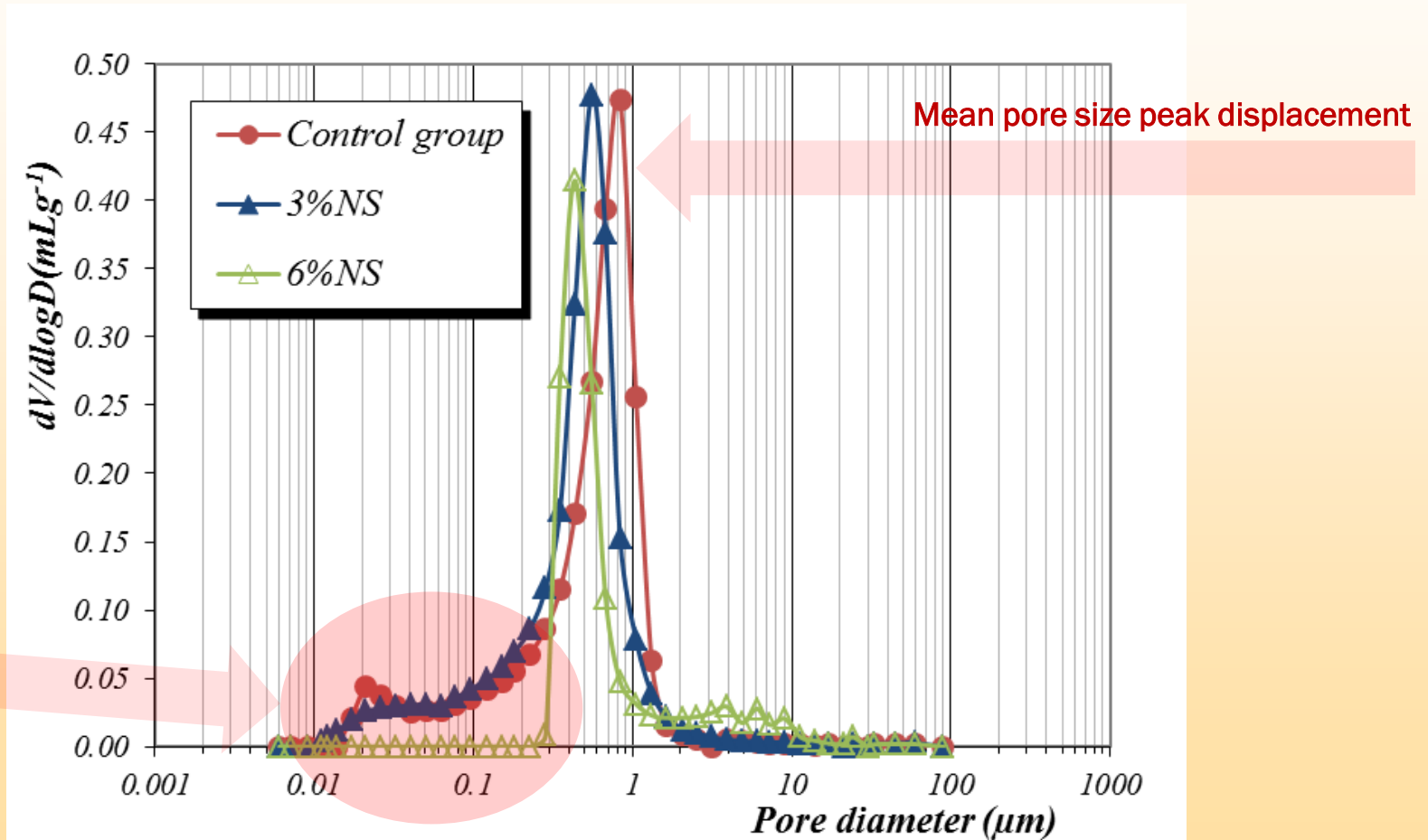
TEM micrograph of NS particles.

NS has been reported to improve both the packing (leading to a reduced porosity) and the mechanical strength thanks to:

- ✓ occurrence of **filling effect**
- ✓ **pozzolanic reaction** between NS and calcium hydroxide (CH) yielding calcium silicate hydrates (C-S-H)

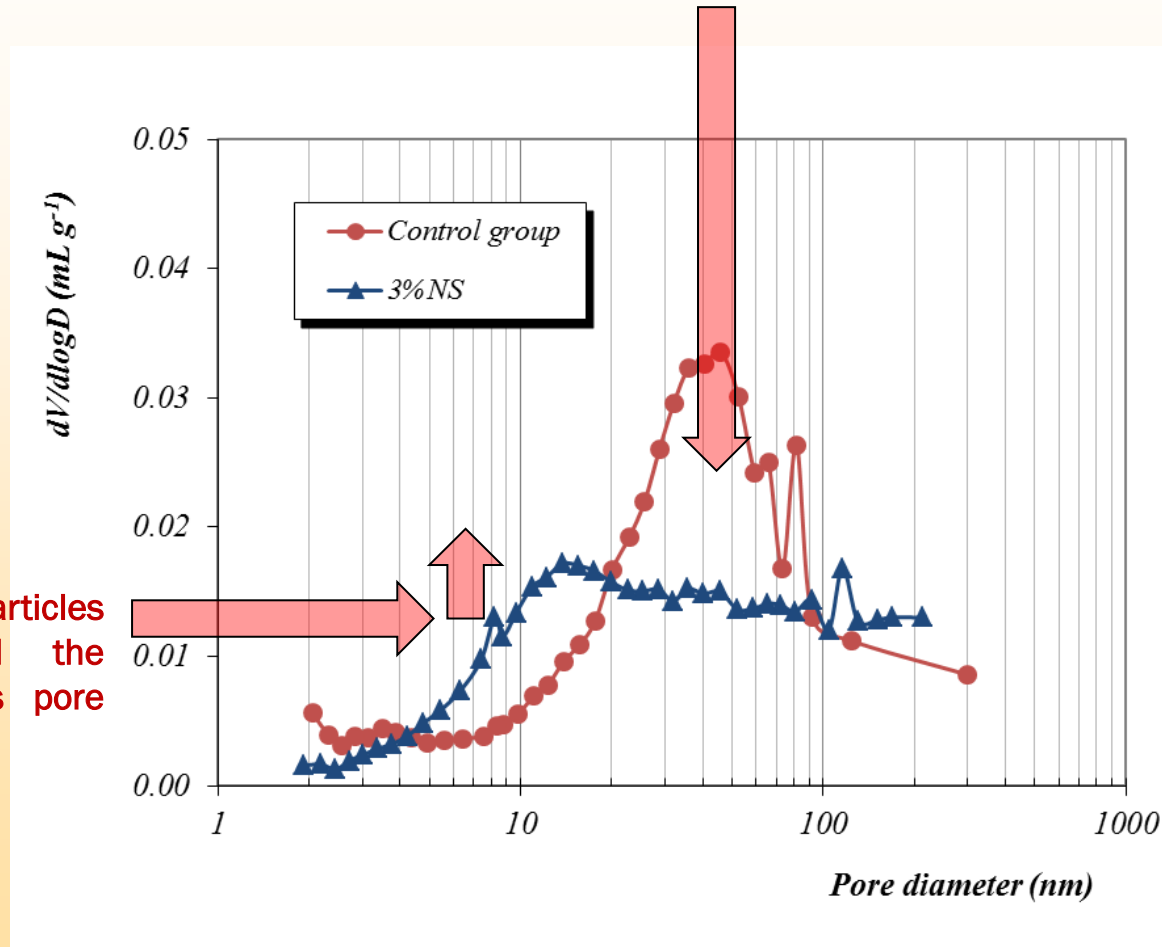


Compressive strengths of the mortars vs. curing time.



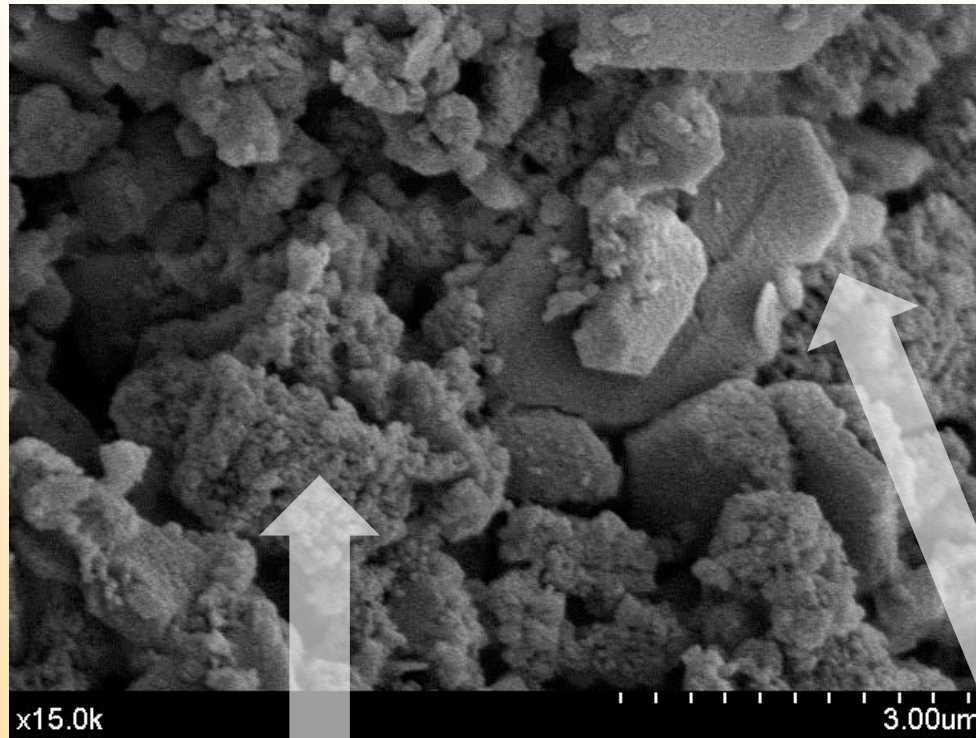
Pore size distributions (MIP) of control group, 3% NS and 6% NS samples.

## Nanofiller effect: reduction of large and medium capillary pores

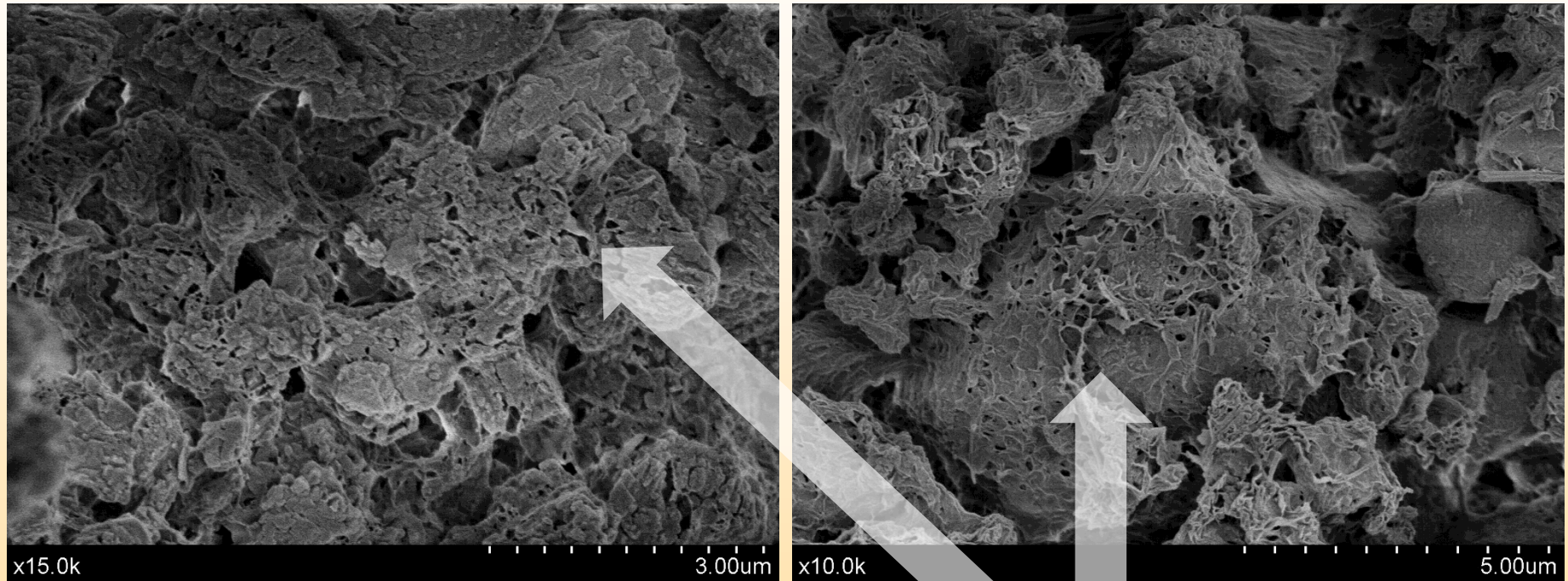


Intercalated NS particles slightly increased the population of this pore range

Pore size distribution in the mesoporous range ( $\text{N}_2$  adsorption isotherms, BJH method): control group and 3% NS samples.



**Plain lime mortar: Scalenohedral calcite crystals and some hexagonal ones of uncarbonated portlandite**



Mortars with 20% of NS: The binding matrix, mainly made of **Calcium silicate hydrates (C-S-H)**, shows a high compactness, and similar **honeycomb** structures.



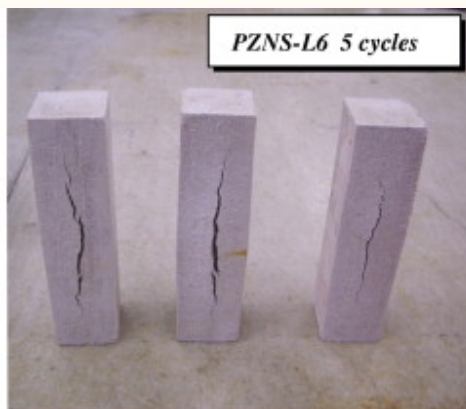
## Pozzolanic addition: nanosilica

### Mortars after freezing–thawing cycles

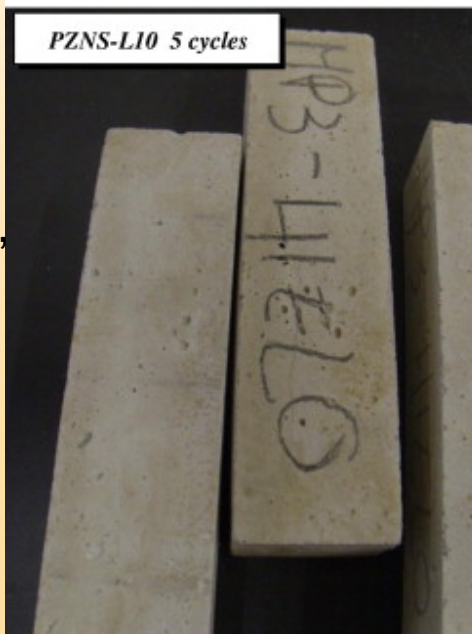
Plain lime mortar,  
after just 1 cycle



Mortar 6 wt.% NS,  
5 cycles



Mortar 10 wt.% NS,  
5 cycles



Mortar 20 wt.% NS,  
5 cycles

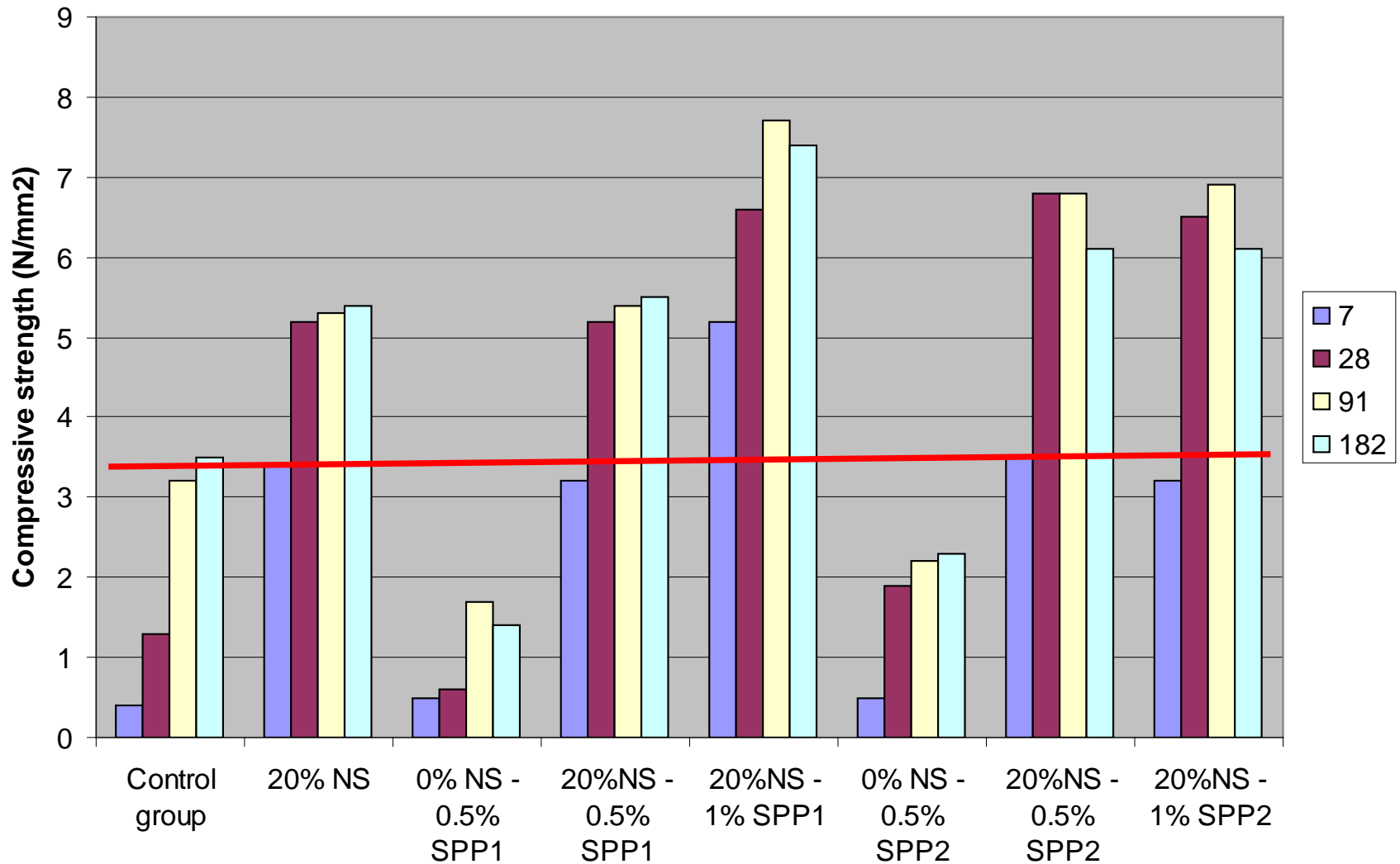




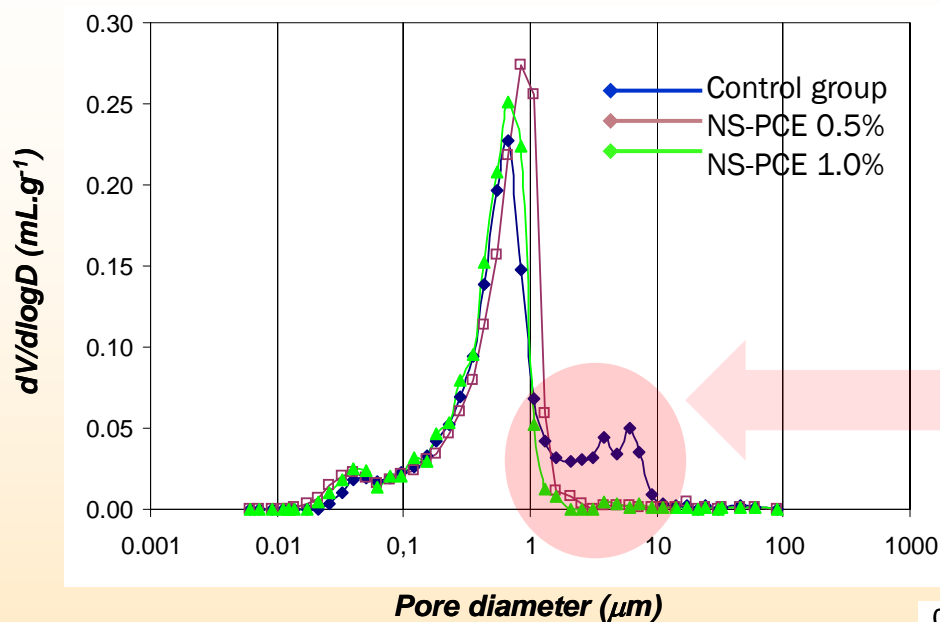
**Combined effect: polycarboxylate ether + nanosilica**



## Combined effect: PCE + NS



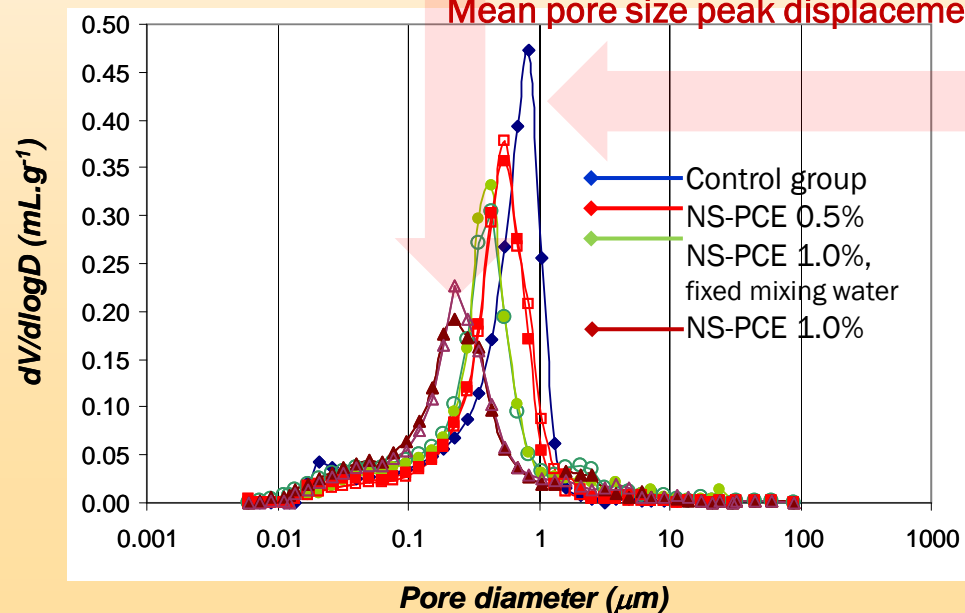
## Combined effect: PCE + NS



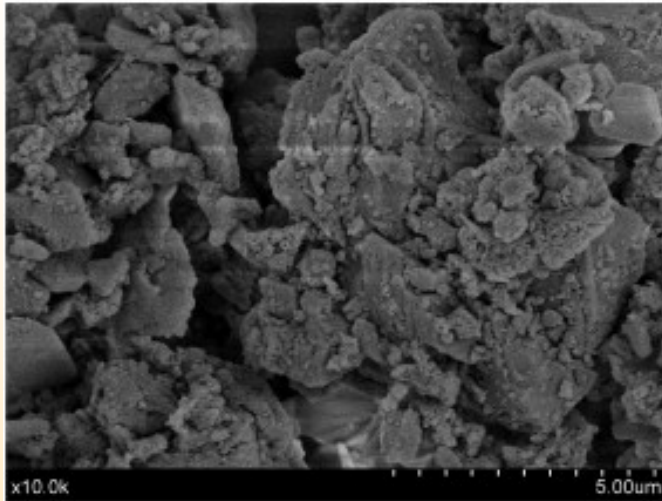
Macropores reduction

Total porosity reduction (AUC)

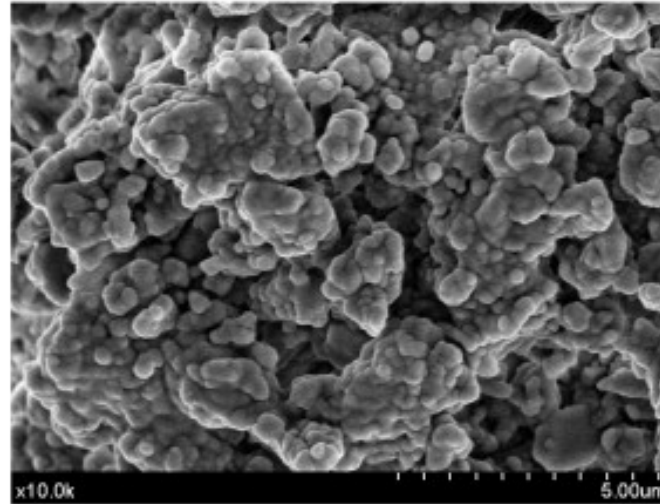
Mean pore size peak displacement



Admixture-free mortar



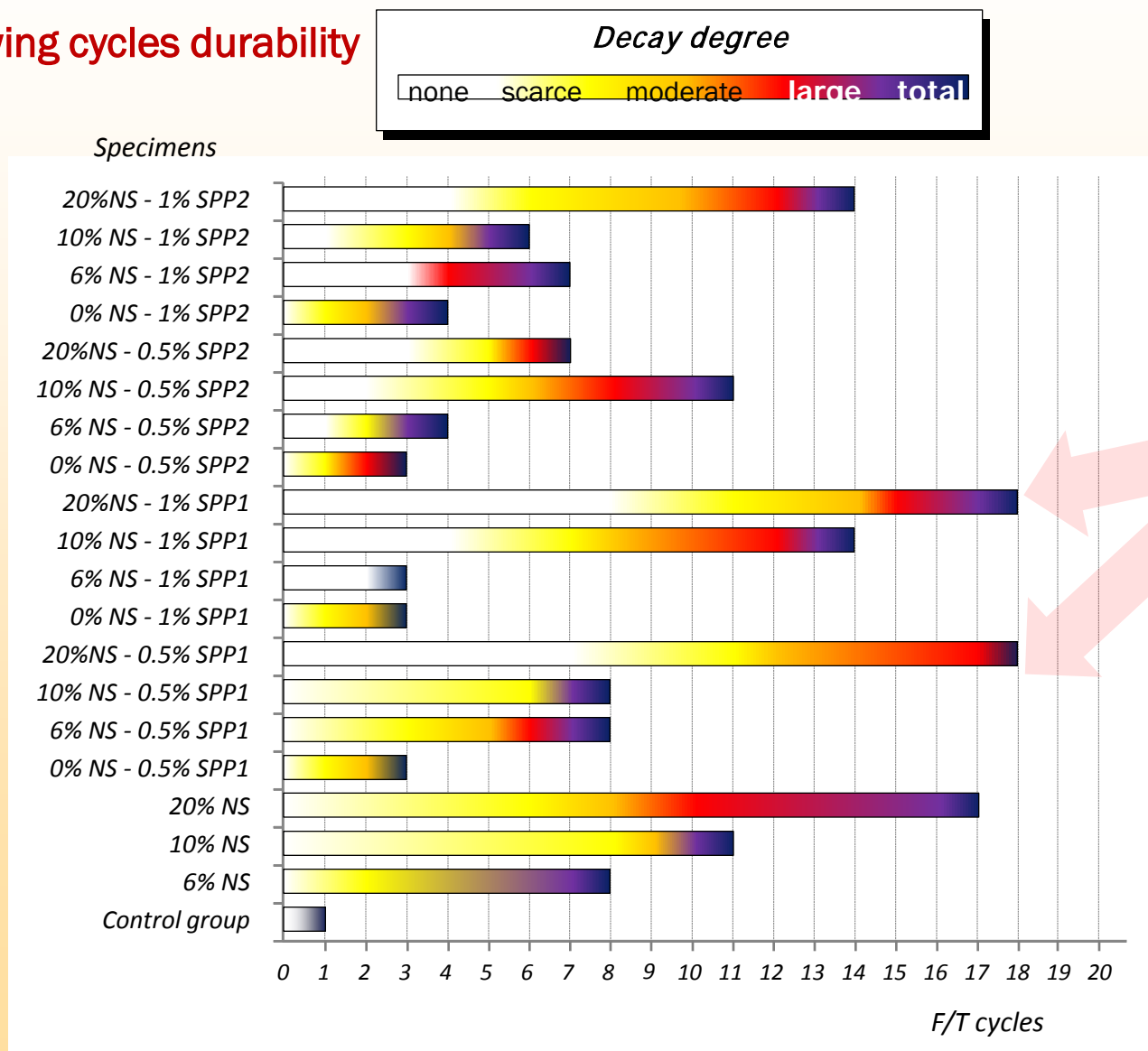
PCE-NS mortar

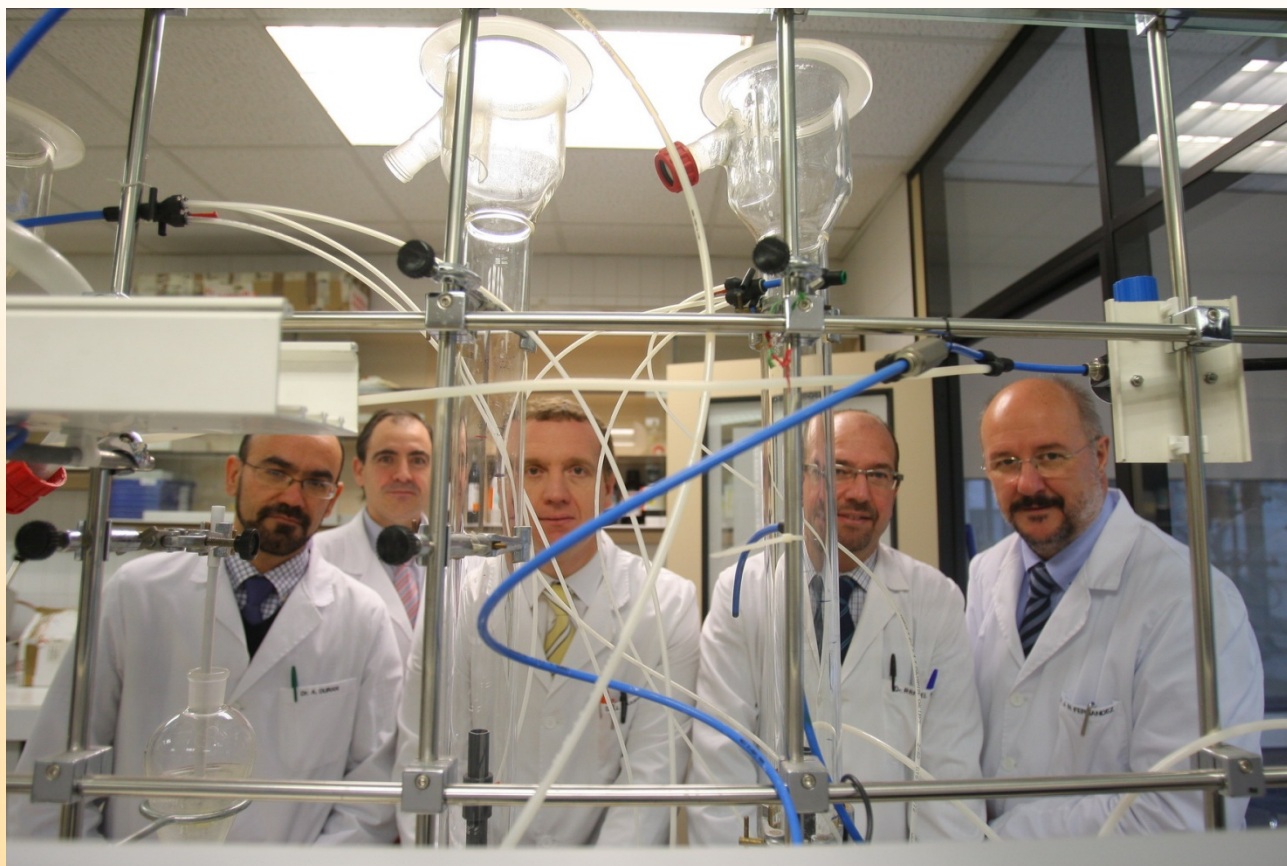


The textural characteristics showed **reduced porosity**, and, on the other hand, the growing of calcite crystals resulted in a **more homogeneous and continuous matrix**, allowing the aggregate particles to be embedded.

## Combined effect: PCE + NS

### freezing–thawing cycles durability







**THANK YOU FOR YOUR ATTENTION**